APPENDIX A

Water Temperature Modeling

TECHNICAL MEMORANDUM

Water Temperature Modeling

PREPARED FOR: Upper Yuba River Studies Program

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Introduction

Water temperature conditions are an important consideration in evaluating the feasibility of introducing Chinook salmon and steelhead above Englebright Dam. This temperature model was developed as a preliminary screening tool to evaluate the effect of incremental flow increases on water temperatures during summer base flow conditions. The model is intended for use as a tool to estimate the effect of increased releases from Jackson Meadows Reservoir on temperatures in the Middle Yuba River, and the effect of increased releases from Lake Spaulding on temperatures in the South Yuba River.

The preliminary results presented in this technical memorandum are for the Middle Yuba River from Milton Dam to approximately 2 miles below Kanaka Creek, and for the South Yuba River from Lake Spaulding to Missouri Bar.

Model Description

The temperature model simulates the flow of water and the accompanying heating and cooling that occur as water moves downstream. Temperature monitoring data collected by the Upper Yuba River Studies Program (UYRSP) are used to characterize the temperatures of releases from Milton Dam and Lake Spaulding. A number of tributary creeks contribute to the flow of both the Middle Yuba and South Yuba rivers downstream of Milton Dam and Lake Spaulding, respectively, and the contributing flows of these creeks have also been included in the model. The simulated physical processes affecting the temperature of water include shortwave solar radiation, longwave radiation, evaporation, and conductive heat transfer across the air-water interface.

The Hydrologic Simulation Program—FORTRAN (HSPF) was used to develop the temperature model for this project. HSPF was selected in order to take advantage of previous work by the U.S. Geological Survey (USGS), which has already developed an HSPF model of the Middle Yuba and South Yuba rivers for the purpose of modeling sediment transport. The input data set for the USGS sediment transport model was used as the basis for the development of the temperature model for this project. HSPF is supported by the U.S. Environmental Protection Agency and is widely accepted in professional practice.

In the HSPF model framework, a river is segmented into linked reaches and flow is simulated by passing water from reach to reach on a user-specified time step. Each reach is assumed to be completely mixed (the temperature is uniform throughout) and is characterized by a uniform channel geometry that relates depth, volume, flow, and surface area. Reach lengths in the model range from 0.52 miles to 3.13 miles, with the average reach length equal to about 1.5 miles. A schematic of the Middle Yuba River representation is shown in Figure 1, and a schematic of the South Yuba River representation is shown in Figure 2.

HSPF simulates the heating and cooling of water by simulating physical processes including shortwave solar radiation, longwave radiation (including both radiation emitted from the water surface and radiation absorbed by the water surface from the atmosphere), evaporation, and conduction across the air-water interface. Meteorological data required to simulate these processes include solar radiation, air temperature, dew point temperature, wind speed, and cloud cover.

Modeling Approach

The temperature model was developed to estimate the effect of incremental flow increases on water temperatures in the Middle Yuba and South Yuba rivers during summer base flow conditions. The model development process included the following steps.

1. Review of available data and selection of summer 2004 as model calibration period
2. Coordination with USGS to use USGS sediment transport model as basis for development of temperature model
3. Development of water balance and estimation of summer 2004 tributary inflows to Middle Yuba and South Yuba rivers
4. Development of summer 2004 meteorological data set
5. Characterization of physical system, including cross-sections and elevation profile
6. Field work to check physical system assumptions
7. Calibration of model using observed stream temperature data

A number of challenges were encountered in the model development process. First, both the Middle Yuba and South Yuba rivers receive significant tributary inflows with unknown flows and temperatures that must be estimated. Second, the hydrology of both rivers can vary significantly from year to year. Finally, the physical system is highly variable. The channel gradient is locally very steep, resulting in wide variation in flow characteristics such as velocity and depth, while the channel morphology is highly variable, with a wide distribution of riffles, runs, pools, and cascades.

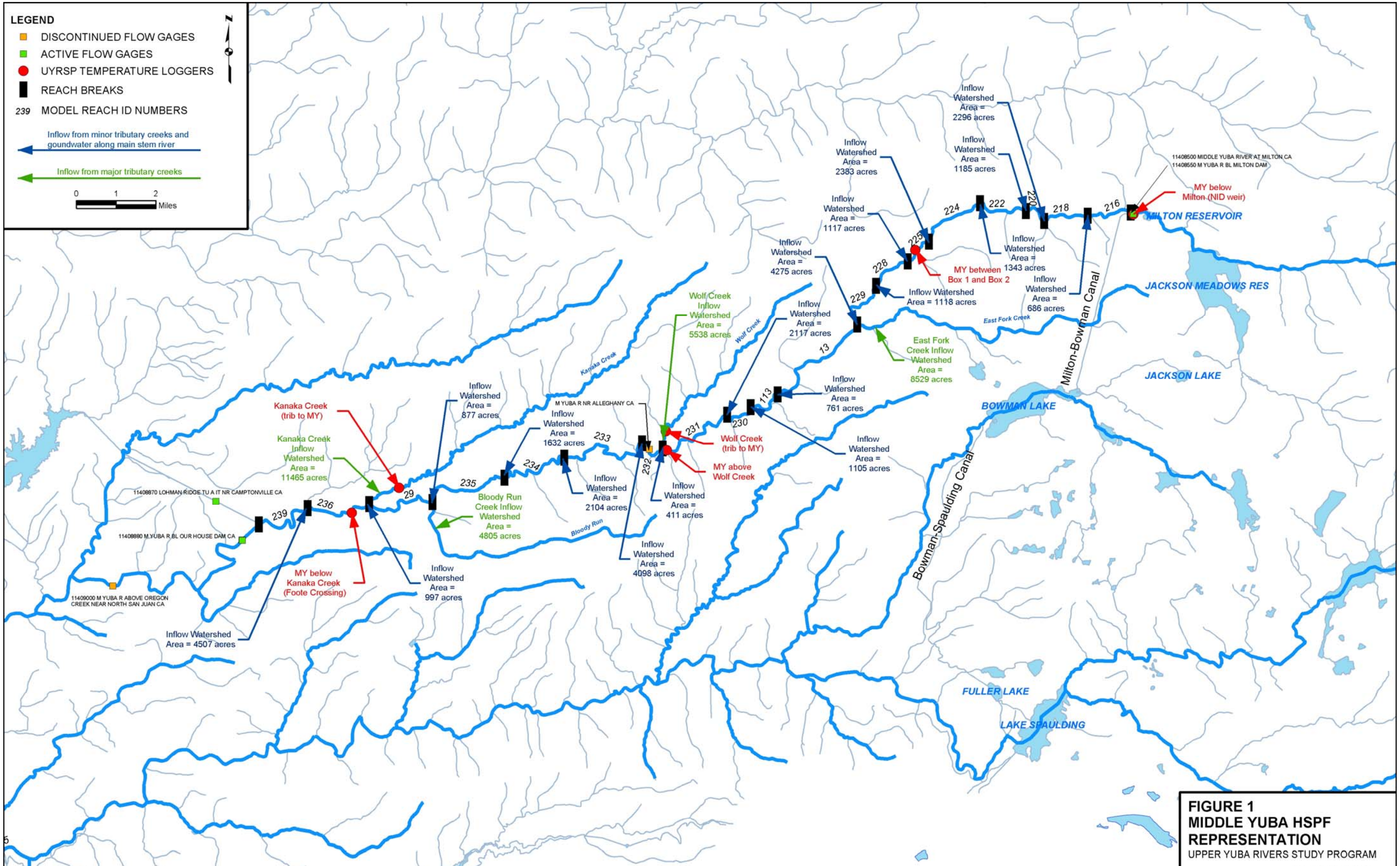

FIGURE 1
MIDDLE YUBA HSPF REPRESENTATION
UPPER YUBA RIVERS STUDY PROGRAM

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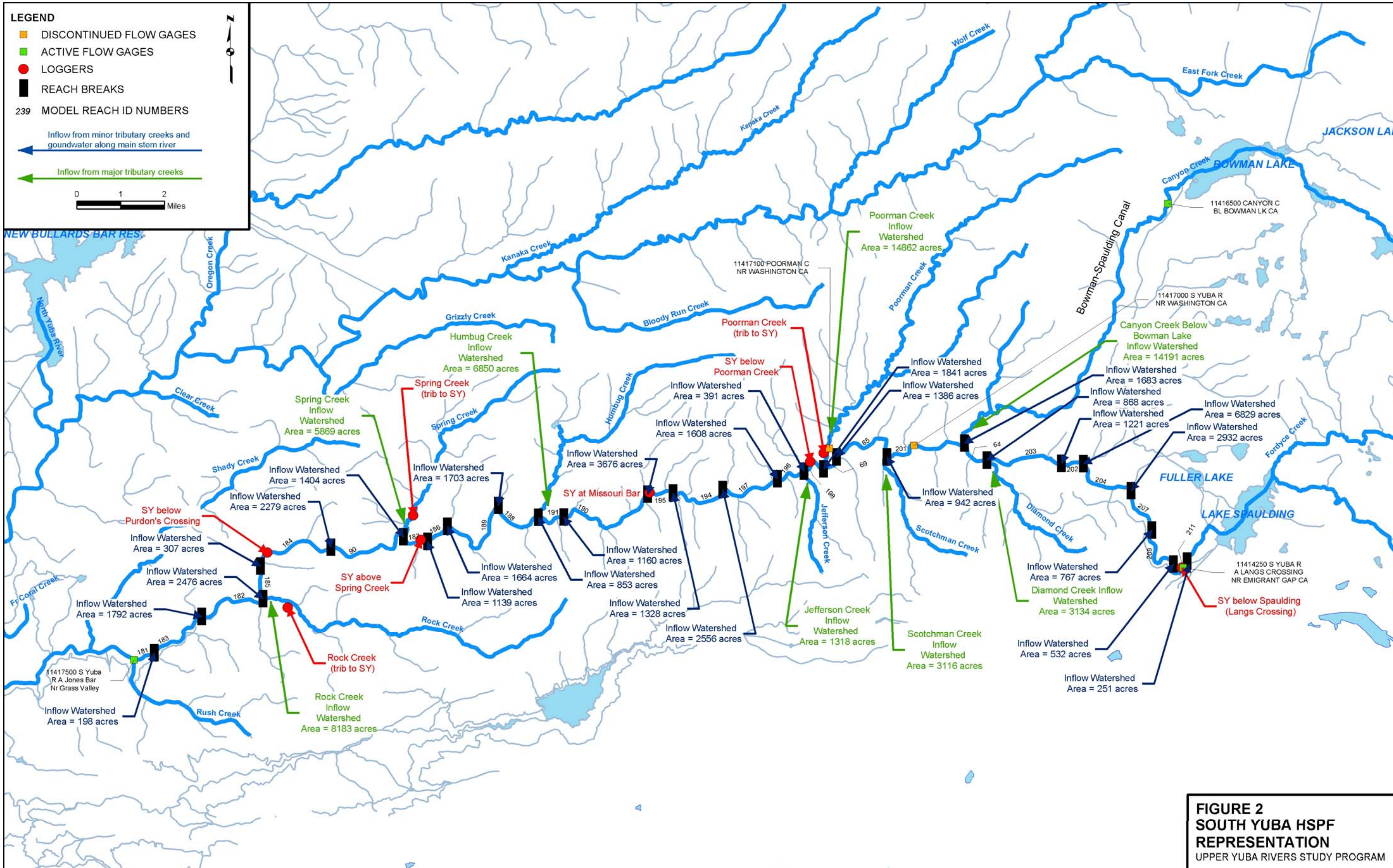

FIGURE 2
SOUTH YUBA HSPF REPRESENTATION
UPPER YUBA RIVERS STUDY PROGRAM
CH2MHILL

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Model Input

Hydrology

The temperature model simulates flow and water temperature during the summer of 2004. The UYRSP has obtained water temperature data for 2003 and 2004. 2005 data were obtained late in the model development process and are available for use in future testing. A review of flow data from 2003 shows that summer flows were considerably higher than average in 2003 due to late spring and summer storms. As a result, flows did not reach a steady summer base flow level until early September. Because summer 2004 flow patterns more closely resembled average base flow conditions, summer 2004 was chosen as the calibration period for the model.

Figures 3 and 4 compare flows on the Middle Yuba River in 2003 and 2004. The Milton Dam release is equal to the flow measured at USGS gage 11408550. The total flow at Our House Dam is assumed to be equal to the sum of the flow below Our House Dam, measured at USGS gage 11408880, and the diversion to the Lohman Ridge Tunnel, measured at USGS gage 11408870.

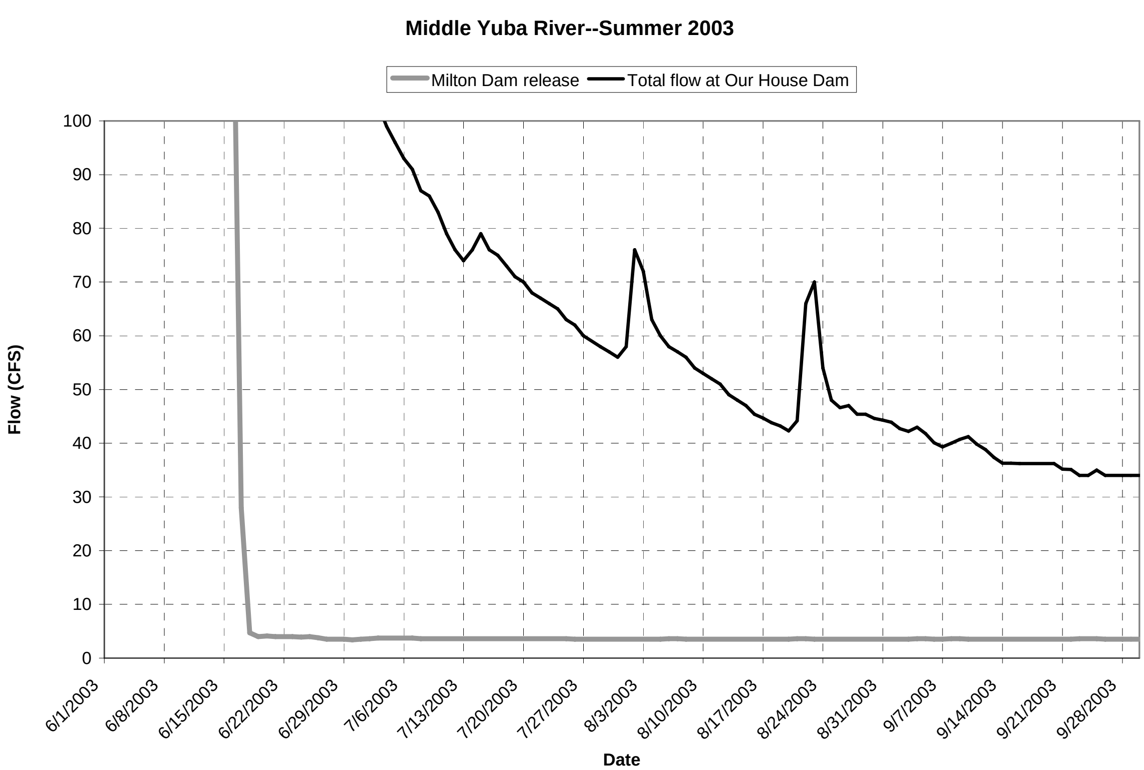

FIGURE 3
Middle Yuba River Flows for Summer 2003

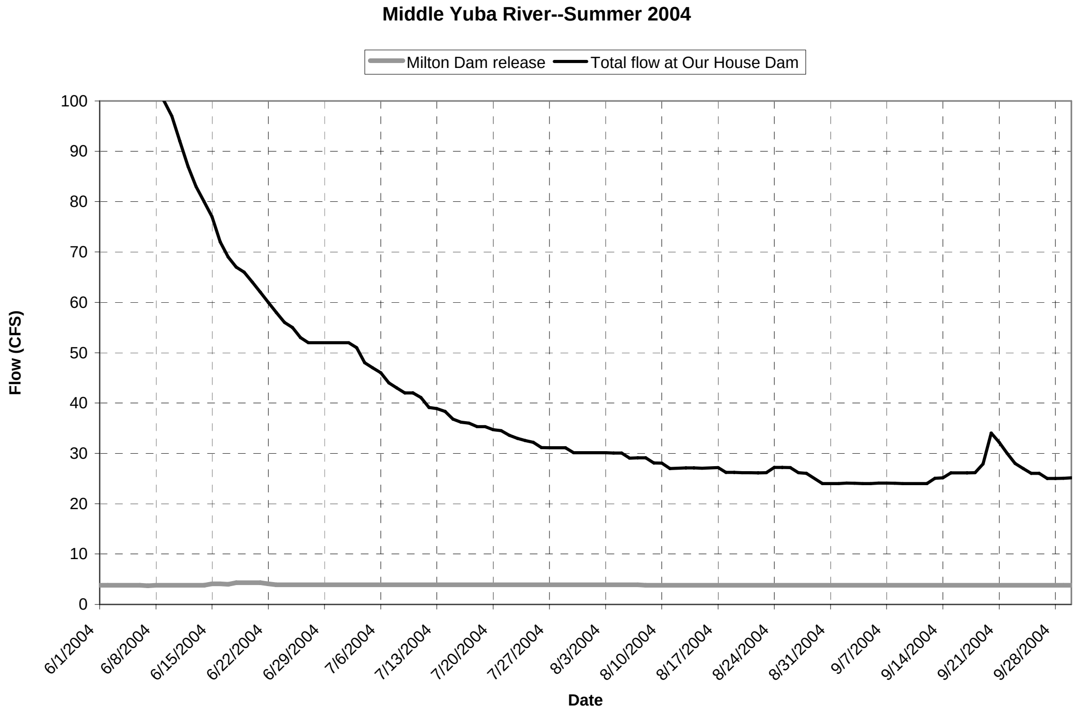

FIGURE 4
Middle Yuba River Flows for Summer 2004

Figures 5 and 6 compare flows on the South Yuba River in 2003 and 2004. The combined release from Lake Spaulding and Bowman Lake is equal to the sum of the flows measured at USGS gages 11414250 and 11416500. The flow at Jones Bar is equal to the flow measured at USGS gage 11417500.

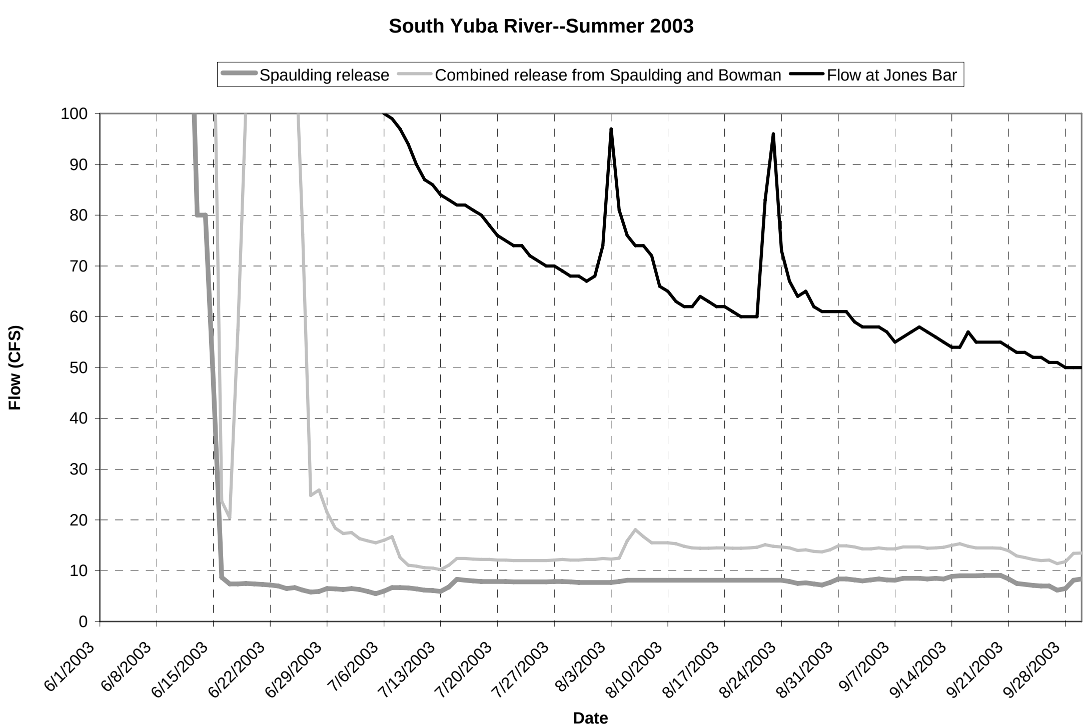

FIGURE 5
South Yuba River Flows for Summer 2003

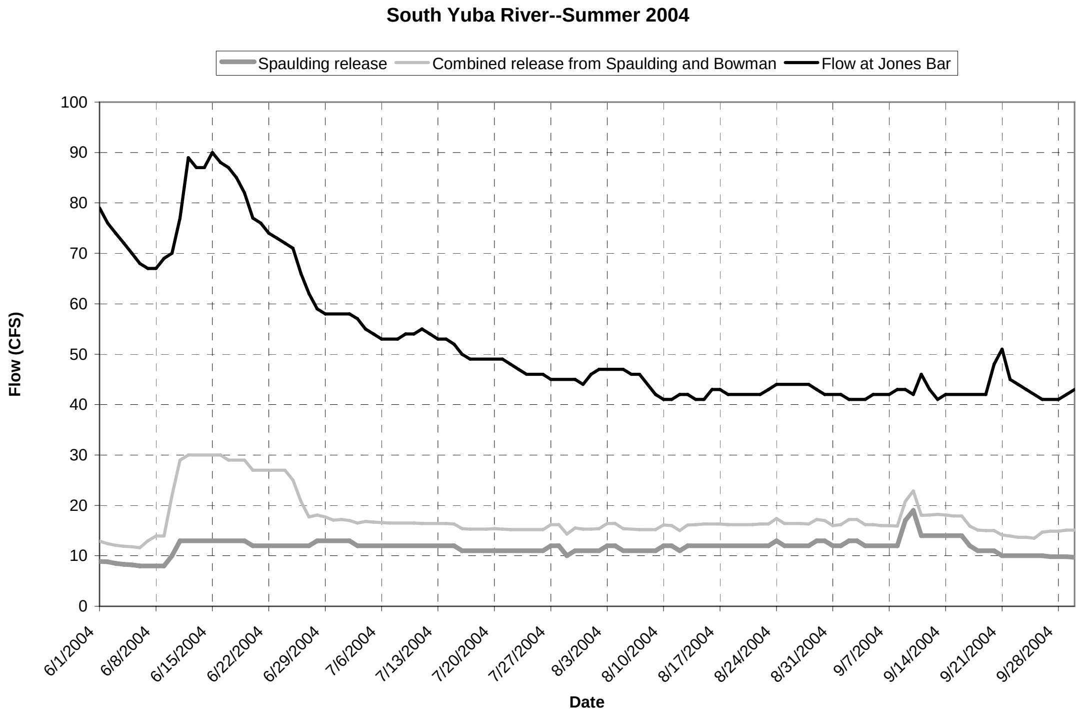

FIGURE 6
South Yuba River Flows for Summer 2004

A comparison of air temperatures in 2003 with 2004 temperatures shows that June-September average temperatures in 2003 were warmer than in 2004; however, 2004 average temperatures are higher than the average for the entire period of record. Table 1 and Table 2 show average monthly air temperatures at Browns Valley and Blue Canyon, which are the two meteorological data stations used in the model.

TABLE 1
Comparison of Average Temperatures at Browns Valley

	Average air temperature (degrees Fahrenheit [°F])					
Year	June	July	August	September	Average June through September	Rank
1989	72.8	78.6	75.7	70.2	74.3	15/17
1990	73.5	80.8	N/A	N/A	77.2	1/17
1991	69.1	79.1	73.7	76.9	74.7	12/17
1992	72.5	76.7	73.7	54.3	69.3	17/17
1993	72.2	76.9	75.9	73.7	74.7	13/17
1994	73.2	79.2	78	73.6	76.0	5/17
1995	69.5	77	78.5	73.8	74.7	11/17
1996	73.1	81.2	79.4	70.6	76.1	3/17
1997	72.4	78.3	76.1	74.1	75.2	8/17
1998	67.7	77.9	80	73	74.7	14/17
1999	71.3	74.9	74.7	74.2	73.8	16/17
2000	76.1	74.7	77.2	72.2	75.1	9/17

TABLE 1
Comparison of Average Temperatures at Browns Valley

	Average air temperature (degrees Fahrenheit [°F])					
Year	**June**	**July**	**August**	**September**	**Average June through September**	**Rank**
2001	75	76.8	77.4	72.7	75.5	6/17
2002	74.2	79.3	76.1	74.5	76.0	4/17
2003	73.9	82.3	75.7	74.4	76.6	2/17
2004	***73.6***	***78.1***	***77.2***	***72.8***	***75.4***	***7/17***
2005	68	82	79.7	69.9	74.9	10/17
Average	72.2	78.5	76.8	71.9	74.9	N/A
Minimum	67.7	74.7	73.7	54.3	69.3	N/A
Maximum	76.1	82.3	80.0	76.9	77.2	N/A

TABLE 2
Comparison of Average Temperatures at Blue Canyon

	Average air temperature (°F)					
Year	**June**	**July**	**August**	**September**	**Average June through September**	**Rank**
1948	N/A	65.2	64.0	61.7	63.7	39/52
1949	62.6	68.1	63.9	63.7	64.6	28/52
1950	58.4	70.4	69.8	60.9	64.9	25/52
1951	63.3	68.6	67.1	66.6	66.4	12/52
1952	54.2	70.2	67.9	63.7	64.0	36/52
1953	53.5	70.1	63.0	67.2	63.4	42/52
1954	55.9	69.6	62.2	60.1	61.9	51/52
1955	59.0	63.5	70.6	62.9	64.0	35/52
1956	59.7	67.8	64.5	63.0	63.8	37/52
1957	63.2	66.4	64.0	63.0	64.1	34/52
1958	56.5	66.7	71.0	63.7	64.5	29/52
1959	63.5	72.8	67.7	59.0	65.7	17/52
1960	67.1	72.1	68.3	66.5	68.5	1/52
1961	66.4	71.2	69.2	60.2	66.7	9/52
1962	61.2	68.6	66.9	64.5	65.3	19/52
1963	56.0	63.5	64.8	63.8	62.0	50/52
1964	54.7	65.9	66.4	60.3	61.8	52/52
1965	57.7	67.2	65.6	57.6	62.0	48/52
1966	60.5	64.8	69.3	62.6	64.3	31/52
1967	58.9	70.5	72.7	65.1	66.8	8/52
1968	63.7	70.2	62.6	63.8	65.1	22/52

TABLE 2
Comparison of Average Temperatures at Blue Canyon

Year	Average air temperature (°F)					Rank
	June	July	August	September	Average June through September	
1969	58.3	69.7	71.5	65.0	66.1	15/52
1970	61.8	70.8	70.4	62.7	66.4	11/52
1971	58.1	69.4	70.7	61.1	64.8	26/52
1972	62.7	70.6	68.4	58.8	65.1	21/52
1973	63.1	69.9	67.2	61.4	65.4	18/52
1974	63.8	65.9	67.6	70.3	66.9	7/52
1975	61.5	67.0	64.2	66.9	64.9	24/52
1976	58.6	68.0	60.0	61.5	62.0	49/52
1977	65.7	67.6	69.1	58.5	65.2	20/52
1978	58.3	67.3	66.6	57.2	62.4	46/52
1979	61.1	65.9	62.5	64.7	63.5	41/52
1980	55.1	67.2	65.9	62.9	62.8	44/52
1981	65.4	69.4	71.8	65.5	68.0	4/52
1982	58.2	65.8	67.1	58.3	62.3	47/52
1983	59.3	62.0	65.9	63.5	62.7	45/52
1984	59.6	71.9	68.7	64.8	66.2	13/52
1985	65.9	69.4	65.4	54.3	63.7	38/52
1986	63.4	65.5	70.5	52.6	63.0	43/52
1987	64.8	62.6	69.7	66.6	65.9	16/52
1988	60.4	72.4	70.7	65.9	67.3	5/52
1989	N/A	N/A	N/A	N/A	N/A	N/A
1990	60.1	69.0	66.4	62.9	64.6	27/52
1991	N/A	N/A	N/A	N/A	N/A	N/A
1992	N/A	N/A	N/A	N/A	N/A	N/A
1993	N/A	N/A	N/A	N/A	N/A	N/A
1994	N/A	N/A	N/A	N/A	N/A	N/A
1995	N/A	N/A	N/A	N/A	N/A	N/A
1996	N/A	71.3	71.6	62.2	68.4	3/52
1997	58.2	67.1	66.4	62.5	63.5	40/52
1998	55.8	68.9	70.9	61.2	64.2	32/52
1999	59.0	65.7	64.4	67.7	64.2	33/52
2000	64.9	65.4	68.7	60.8	64.9	23/52
2001	62.0	67.9	70.7	65.9	66.6	10/52
2002	63.8	72.0	69.0	64.5	67.3	6/52
2003	64.8	73.0	66.9	68.9	68.4	2/52
2004	***63.1***	***69.5***	***69.1***	***62.9***	***66.2***	***14/52***
2005	54.9	72.4	70.4	59.6	64.3	30/52

TABLE 2
Comparison of Average Temperatures at Blue Canyon

Year	Average air temperature (°F)					Rank
	June	July	August	September	Average June through September	
Average	60.5	68.3	67.5	62.7	64.8	N/A
Minimum	53.5	62.0	60.0	52.6	61.8	N/A
Maximum	67.1	73.0	72.7	70.3	68.5	N/A

Note: Temperature records at Blue Canyon not available June 1948, 1989, 1991-1995.

As shown in Figure 1, no active flow gages exist on the Middle Yuba River between Milton Dam and Our House Dam. However, the flow records show that there are significant gains in flow between these gages, even during the summer of 2004 when precipitation was negligible. These gains in flow are due to tributary inflows, groundwater inflows, or both.

Figure 2 shows that no active flow gages exist on the South Yuba River between Lake Spaulding and Jones Bar. However, there are also significant flow gains between these gages. As with the Middle Yuba River, these gains are due to tributary flows and groundwater inflows.

To estimate tributary flows to the Middle Yuba River, the increase in flow between Milton Dam and Our House Dam was partitioned into inflows to each of the model reaches based on the watershed area contributing to each reach. For example, if 5 percent of the total watershed area between Milton Dam and Our House Dam ran off into the section of the river represented by reach 224, then 5 percent of the total difference in flow between Milton Dam and Our House Dam was assigned as an inflow to reach 224. Four major tributary creeks, including East Fork Creek, Wolf Creek, Bloody Run Creek, and Kanaka Creek, have sizeable watershed areas of their own and were assigned separate inflows based on their watershed areas. The schematic shown in Figure 1 shows the watershed area associated with each reach, as well as the watershed areas of each of the four major tributary creeks.

The watershed area approach was modified to assume that 75 percent of the total increase in flow between Milton Dam and Our House Dam was allocated at or above Wolf Creek, with the remainder allocated below Wolf Creek. USGS gage 11408700 on the Middle Yuba River at Alleghany, which was in operation from 1957 to 1966, shows that during water years comparable to 2004 about 75 percent of the gain in flow between Milton Dam and Our House Dam during July and August occurs at or above Wolf Creek.

To estimate tributary flows to the South Yuba River, the difference between the upper reservoir releases and the flow at Jones Bar also was apportioned on a watershed area basis. Tributary flows were assigned to each reach on the main stem of the South Yuba River, major tributary creeks including Diamond, Scotchman, Poorman, Jefferson, Humbug, Spring, and Rock creeks, and the portion of Canyon Creek between Bowman Dam and the confluence with the South Yuba River. The schematic shown in Figure 2 shows the watershed area associated with each reach, as well as the watershed area of each of the tributary creeks and the portion of Canyon Creek below Bowman Dam.

The inflow from Rock Creek was not developed using a watershed area approach. A small reservoir on Rock Creek (Lake Vera) diverts much of the creek's flow, so a constant flow of 1 cubic foot per second (cfs) from Rock Creek was assumed for the length of the analysis period.

The watershed area approach used on the South Yuba River was modified after a comparison of results with two historic gage flow records: USGS 11417000 on the South Yuba River near Washington, which was in operation from 1942 to 1972, and USGS 11417100 on Poorman Creek, which was in operation from 1961 to 1971. An analysis of these records during water years comparable to 2004 showed that approximately 29 percent of the gain in flow between the upper reservoirs and Jones Bar during July and August occurs upstream of Scotchman Creek, while approximately 28 percent of the gain in flow during July and August is contributed by Poorman Creek. The watershed area approach was modified so that 28 percent of the gain in flow is contributed by Poorman Creek, 29 percent is split among reaches and tributaries above Scotchman Creek on a watershed area basis, and the remaining gain is split among reaches and tributaries below Scotchman Creek (with the exception of Poorman Creek), also on a watershed area basis.

Flow gages used to develop hydrologic inputs to the model are listed below in Tables 3 and 4.

TABLE 3
Flow Gages Used to Develop Middle Yuba River Inflows

USGS Gage Name	USGS Gage Number	Period of Record Used	Comments
Middle Yuba River Below Milton Dam	11408550	6/1/2004 to 9/30/2004	Used to determine release from Milton Dam
Lohman Ridge Tunnel at intake	11408870	6/1/2004 to 9/30/2004	Used to estimate total flow at Our House Dam
Middle Yuba River below Our House Dam	11408880	6/1/2004 to 9/30/2004	Used to estimate total flow at Our House Dam
Middle Yuba near Alleghany, CA	11408700	10/1/1957 to 9/30/1964	Used to estimate proportion of tributary flows at or above Wolf Creek from 1957-1964
Middle Yuba River at Milton, CA	11408500	10/1/1957 to 9/30/1964	Used to determine release from Milton Dam from 1957to 1964
Middle Yuba River above Oregon Creek near North San Juan, CA	11409000	10/1/1957 to 9/30/1964	Used to estimate total flow at Our House Dam from 1957 to 1964—Our House Dam and Lohman Ridge Tunnel not in operation until 1969

TABLE 4
Flow Gages Used to Develop South Yuba River Inflows

USGS Gage Name	USGS Gage Number	Period of Record Used	Comments
South Yuba River at Langs Crossing	11414250	6/1/2004 to 9/30/2004	Used to determine release from Lake Spaulding
		10/1/1965 to 9/30/1972	Used to estimate proportion of tributary flows at Poorman Creek, above Scotchman Creek

TABLE 4
Flow Gages Used to Develop South Yuba River Inflows

USGS Gage Name	USGS Gage Number	Period of Record Used	Comments
Canyon Creek below Bowman Lake	11416500	6/1/2004 to 9/30/2004	Used to determine release from Bowman Lake
		10/1/1965 to 9/30/1972	Used to estimate proportion of tributary flows at Poorman Creek, above Scotchman Creek
South Yuba River at Jones Bar	11417500	6/1/2004 to 9/30/2004	Used to determine South Yuba River flow at Jones Bar
		10/1/1965 to 9/30/1972	Used to estimate proportion of tributary flows at Poorman Creek, above Scotchman Creek
South Yuba River near Washington	11417000	10/1/1965 to 9/30/1972	Used to estimate proportion of tributary flows above Scotchman Creek
Poorman Creek near Washington	11417100	10/1/1965 to 9/30/1971	Used to estimate proportion of tributary flows at Poorman Creek

Meteorological Data

Because the sediment transport model obtained from USGS only contained input data through 2003, it was necessary to develop a new meteorological input data set for summer 2004. Meteorological data sets from the following sources were inventoried:

- California Irrigation Management Information System (CIMIS)
- California Data Exchange Center (CDEC)
- National Climatic Data Center (NCDC)
- Western Regional Climate Center (WRCC)

After checking data from each of the above sources, a single data set from the CIMIS Browns Valley monitoring station was selected for use throughout the study area. This data set includes measurements of solar radiation, air temperature, dew point temperature, and wind speed. CIMIS data were selected because it is considered good practice to obtain all meteorological data from a single source, and CIMIS offers the most complete data set available; in addition, CIMIS is considered to be more reliable than other data sources. Cloud cover, which is the other meteorological input required by the model, was not available from any data source and was estimated as described below.

Although CIMIS Browns Valley data was used throughout the study area for solar radiation, air temperature, and wind speed, it was necessary to introduce another data set for dew point temperature in the upper reaches of the model. (It is reasonable to use a single air temperature data set throughout the study area because HSPF adjusts air temperatures based on elevation using a lapse rate calculation.) Initial modeling results showed that when the CIMIS dew point temperature data set were applied throughout the study area, simulated water temperatures in higher elevation reaches were consistently higher than observed temperatures, while simulated temperatures in lower reaches generally agreed with observed data. It was hypothesized that the high simulated temperatures in the upper reaches resulted from using dew point temperatures that overstated the amount of moisture in the air and did not allow for adequate evaporative cooling; the CIMIS Browns Valley station is located at an elevation of 940 feet and may not be representative of moisture conditions at higher elevations, where the air is generally drier. After replacing the CIMIS data set with a set of dew point temperatures from the NCDC monitoring station at Blue Canyon (elevation 5,276 feet), it was found that simulated water temperatures matched observed temperatures more closely.

The model uses an estimate of 20 percent cloud cover throughout the study area. HSPF is not sensitive to cloud cover, which causes a slight increase in absorption of longwave radiation from the atmosphere (cloud cover does not affect solar radiation in the model), and 20 percent was chosen to approximate the degree of cloud cover caused by afternoon thunderstorm activity during the summer months. Table 5 summarizes the meteorological inputs used in the model.

TABLE 5
Meteorological Data Sets Used in Temperature Model

Meteorological Input	Source of Data	Locations Used
Solar radiation	CIMIS Browns Valley	Entire study area
Air temperature	CIMIS Browns Valley	Entire study area
Dew point temperature	CIMIS Browns Valley	Middle Yuba: from 2.4 miles above Wolf Creek to Our House Dam
		South Yuba: from 1.85 miles above Diamond Creek to Missouri Bar
Dew point temperature	NCDC Blue Canyon	Middle Yuba: from Milton Dam to 2.4 miles above Wolf Creek
		South Yuba: From Lake Spaulding to 1.85 miles above Diamond Creek
Wind speed	CIMIS Browns Valley	Entire study area
Cloud cover	Estimated	Entire study area

Water Temperature

Water temperature data collected for the UYRSP were used in the temperature model to establish boundary conditions and to calibrate simulated temperatures. A complete description of the temperature monitoring program is available in an accompanying technical memorandum.

Temperature data collected just downstream of Milton Dam, at the mouth of Wolf Creek and at the mouth of Kanaka Creek, were used to establish boundary conditions on the Middle Yuba River. Because temperature data were not available for East Fork Creek and Bloody Run Creek, each of these inflows was set equal to a neighboring creek with a similar elevation profile. The Wolf Creek record was used to set the inflow temperature of East Fork Creek and the Kanaka Creek record was used to set the inflow temperature of Bloody Run Creek.

Temperature data collected at Langs Crossing and at the mouth of Poorman Creek were used to establish boundary conditions on the South Yuba River. As was the case on the Middle Yuba River, temperature data were not available for a number of significant tributaries and these tributaries were set equal to neighboring creeks with similar elevation profiles. The Poorman Creek record was used to set the temperatures of Diamond, Scotchman, and Jefferson creeks. Although temperature data were not available at the mouth of Canyon Creek for summer 2004, a record was available for 2003, and this record was used to estimate 2004 Canyon Creek temperatures through regression with the Wolf Creek record. The Wolf Creek record was used for the regression because the range of diurnal temperature variation observed at Canyon Creek in 2003 was closer to the range observed at Wolf Creek than any other tributary creek.

All tributary flows on the Middle Yuba River other than those associated with the four major tributary creeks were assumed to have a constant temperature of 55°F. Estimating the temperatures of minor inflows is difficult because no monitoring data are available for any minor creeks and because of uncertainty as to whether minor inflows along the main stem river are due to small creeks or to groundwater inflows. An experiment using the Wolf Creek and Kanaka Creek records to approximate the temperatures of minor inflows yielded good results in the downstream reaches of the study area, but resulted in water temperatures that were too high in the upstream reaches. In the experiment, the Wolf Creek record was used for all inflows upstream of Wolf Creek because no higher-elevation record was available; simulation results indicated that this record was not appropriate for the uppermost inflows because its elevation was too low and resulting temperatures were therefore too warm. A temperature of 55°F was chosen as the inflow temperature because the average daily minimum temperature at the Box Canyons monitoring location is about 55°F, and temperature monitoring data show that the average temperatures of tributary inflows are generally equal to the average daily minimum temperatures of the main stem river. The 55°F assumption is continued downstream because below East Fork Creek minor inflows are so small in comparison to the flow of the main stem river that the temperature of the minor inflows has a negligible impact on simulated temperatures.

The same approach used to estimate the temperatures of minor inflows to the Middle Yuba River was also applied on the South Yuba River. Temperature records at the Poorman Creek confluence with the South Yuba River, which is the first location below Lake Spaulding for which monitoring data are available, show that the average daily minimum temperature on the South Yuba River was about 65°F. As a result, 65°F was used as the temperature of all minor inflows along the South Yuba River.

Water temperature data collected along the main stems of the Middle Yuba and South Yuba rivers were used for model calibration. Temperature monitoring points used for calibration and verification on the Middle Yuba River include loggers between Box Canyons 1 and 2, above the confluence with Wolf Creek, and below the confluence with Kanaka Creek. Temperature monitoring points used for calibration and verification on the South Yuba River include loggers below Poorman Creek and at Missouri Bar. Water temperature monitoring locations used in the model are listed in Tables 6 and 7.

TABLE 6
Water Temperature Monitoring Locations and Records Used in Middle Yuba River Temperature Model

Monitoring Location	Period of Record	Comments
Below Milton Dam	6/1/2004 to 9/13/2004	Used to set upstream boundary condition
Between Box Canyons 1 and 2	7/9/2004 to 10/14/2004	Used for calibration
Above Wolf Creek	4/28/2004 to 9/16/2004	Used for calibration
Below Kanaka Creek	4/28/2004 to 9/16/2004	Used for calibration
Wolf Creek (tributary)	6/1/2004 to 9/16/2004	Used to set inflow temperatures of Wolf Creek and East Fork Creek
Kanaka Creek (tributary)	4/28/2004 to 9/16/2004	Used to set inflow temperatures of Kanaka Creek and Bloody Run Creek

TABLE 7
Water Temperature Monitoring Locations and Records Used in South Yuba River Temperature Model

Monitoring Location	Period of Record	Comments
Below Lake Spaulding	4/29/2004 to 9/13/2004	Used to set upstream boundary condition
Below Poorman Creek	4/29/2004 to 9/13/2004	Used for calibration
Missouri Bar	4/29/2004 to 9/13/2004	Used for calibration
Canyon Creek (tributary)	6/19/2003 to 9/13/2003	Used to develop regression relationship with Wolf Creek to estimate Canyon Creek 2004 inflow temperatures
Poorman Creek (tributary)	4/29/2004 to 9/15/2004	Used to set inflow temperatures of Diamond, Scotchman, Poorman, and Jefferson Creeks.
Wolf Creek (tributary)	6/17/2004 to 9/13/2004	Used to estimate Canyon Creek 2004 inflow temperatures
	6/19/2003 to 9/13/2003	Used to develop regression relationship with Canyon Creek to estimate Canyon Creek 2004 inflow temperatures

Physical System Representation

Channel Cross-Sections

For the purpose of developing the temperature model, the channel cross-sections in the original HSPF model obtained from USGS were replaced by an entirely new set of cross-sections. The original USGS cross-sections were surveyed for the purpose of sediment transport modeling, the bulk of which occurs during high-flow runoff events during the winter and spring. As a result, the flow-stage relationship was not well-defined for low-flow conditions. When the USGS cross-sections were used to model summer flows, simulated channels were wider and shallower on average than observed in the field studies. The wide and shallow simulated channels allowed the simulated stream flows to heat rapidly and cool quickly, resulting in a range of daily temperature variation that was several times greater than the observed range of variation.

The new cross-sections were developed using field measurements and habitat survey results. Habitat surveys by the UYRSP characterized the length of the Middle Yuba and South Yuba rivers by channel type. Most of the rivers' reaches fell into one of the following four habitat types: riffle, run, shallow pool, or deep pool. To develop a new set of cross-sections, representative cross-sections were surveyed for each of the four major habitat types. Then, a composite cross-section was developed for each reach based on the percentage of habitat types within that reach. For example, if the percentage of habitat types within a particular reach was heavily weighted towards deep pools, then the composite cross-section developed for that reach was weighted towards the representative deep pool cross-section. Tables 8 and 9 give the percentage of each habitat type in each reach.

TABLE 8
Percentage of Habitat Types in Model Reaches: Middle Yuba River

Reach	Length (miles)	Vertical Drop (feet)	% Riffle	% Run	% Shallow Pool	% Deep Pool
Milton Dam to East Fork Creek						
216	0.6	82	22.1	37.9	12.8	27.1
217	0.6	82	22.1	37.9	12.8	27.1
218	1.13	105	15.2	36.3	17.2	31.3
220	0.72	128	30.6	30.9	5.6	32.9
222	1.45	154	20.3	46.6	15.8	17.3
224	1.67	276	19.4	24.7	25.9	30.0
225	0.52	85	16.4	13.2	40.4	30.0
228	1.38	226	26.7	36.2	18.9	18.2
229	1.47	528	43.2	17.6	10.9	28.3
East Fork Creek to Wolf Creek						
13	3.13	659	39.3	16.9	10.0	33.7
113	1.04	92	41.7	22.7	6.8	28.8
230	0.92	108	38.0	30.4	4.6	27.0
231	2.36	164	38.1	29.5	16.1	16.3
Wolf Creek to Bloody Run Creek						
232	0.79	66	32.0	41.8	9.7	16.6
233	2.88	187	31.3	17.8	9.8	41.1
234	2.39	197	31.9	20.8	24.5	22.8
235	2.33	213	33.1	19.6	23.2	24.0
Bloody Run Creek to Kanaka Creek						
29	2.04	154	34.4	19.8	26.5	19.3
Kanaka Creek to Our House Dam						
236	1.74	69	26.7	27.9	21.1	24.3
239	2.1	119	11.3	46.5	23.0	19.2

TABLE 9
Percentage of Habitat Types in Model Reaches: South Yuba River

Reach	Length (miles)	Vertical Drop (feet)	% Riffle	% Run	% Shallow Pool	% Deep Pool
Lake Spaulding to Diamond Creek						
211	0.33	80	42.8	5.4	28.5	23.4
210	0.33	80	42.8	5.4	28.5	23.4
209	1.39	308	22.3	22.3	25.4	30
207	1.49	400	53.0	7.1	12.8	27.1
204	1.2	357	44.0	14.4	24.2	17.4
202	0.81	131	46.8	13.2	18.3	21.7
203	1.85	236	24.9	46.9	7.3	20.9
Diamond Creek to Canyon Creek						
64	0.77	43	24.4	30.7	14.7	30.2
Canyon Creek to Scotchman Creek						
201	2.06	167	46.0	15.3	11.7	27.1
Scotchman Creek to Poorman Creek						
65	1.79	118	30.5	15.3	24.2	30.0
69	0.49	23	27.4	25.7	16.9	30.0
Poorman Creek to Jefferson Creek						
198	0.67	36	28.4	12.4	29.2	30.0
Jefferson Creek to Missouri Bar						
196	0.85	16	29.4	20.0	20.6	30
197	1.36	98	26.0	15.4	28.7	30.0
194	1.48	82	18.2	39.8	12.0	30.0
195	0.56	10	19.4	32.8	21.8	26.0

On the Middle Yuba River, three sets of representative cross-sections were surveyed in the field to attempt to better characterize the spatial variability of the river channel. Cross-sections were surveyed between Box Canyons 1 and 2, above Wolf Creek, and below Kanaka Creek. Each cross-section was adjusted to a simplified geometric shape for easier use in the model. In some cases, cross-sectional dimensions were estimated based on field observations.

Cross-sections of deep and shallow pools were not available for the Middle Yuba River at Kanaka Creek because no pools were surveyed at this location. The pool dimensions at Kanaka Creek were assumed to be the same as the pool dimensions at Wolf Creek. This assumption was confirmed by field observations near Kanaka Creek.

On the South Yuba River, cross-sections were surveyed at Canyon Creek, Poorman Creek, Missouri Bar, and Spring Creek. A single set of cross-sections was applied throughout the South Yuba River study area; this set includes cross-sections surveyed at Poorman Creek and Spring Creek. A single set was used throughout the study area because this set was determined to be more representative of typical channel geometry on the South Yuba River than any of the other cross-sections obtained during the field survey.

The locations where the cross-sections were applied in the model are summarized in Tables 10 and 11.

TABLE 10
Representative Cross-sections Used in Middle Yuba River Temperature Model

Survey Location	Habitat Type	Method of Assessment	Location Applied in Model
Between Box Canyons 1 and 2	Riffle	Surveyed	Milton Dam to East Fork Creek
	Run	Surveyed	
	Shallow Pool	Estimated	
	Deep Pool	Estimated	
Wolf Creek	Riffle	Surveyed	East Fork Creek to 2.3 miles above Bloody Run Creek
	Run	Surveyed	
	Shallow Pool	Surveyed	East Fork Creek to Our House Dam
	Deep Pool	Estimated	
Kanaka Creek	Riffle	Surveyed	2.3 miles above Bloody Run Creek to Our House Dam
	Run	Surveyed	

TABLE 11
Representative Cross-sections Used in South Yuba River Temperature Model

Survey Location	Habitat Type	Method of Assessment	Location Applied in Model
Poorman Creek	Run	Surveyed	Lake Spaulding to Missouri Bar
	Shallow Pool	Surveyed	
	Deep Pool	Estimated	
Spring Creek	Riffle	Surveyed	Lake Spaulding to Missouri Bar

The cross-sections were modeled using the assumption of uniform flow for the riffle and run habitat types, and the assumption of flow controlled by a broad-crested weir for the shallow and deep pools. The riffle and run sections were both modeled as channels undergoing uniform flow with a Manning's n of 0.075. Because many of the pools are deep and wide even at very low flows (less than 10 cfs), it was not possible to develop a reasonable simulation for the pools using the assumption of uniform flow. Most of the pools are deep and wide for most of their lengths and then narrow to shallow outlets at their downstream ends. It was assumed that the shallow, narrow outlet controls the flow and essentially acts like a broad-crested weir. The flow properties of the pools assume the shallow pools are controlled by a 2- to 3-foot-high broad-crested weir and the deep pools by a 4- to 5-foot-high broad-crested weir. In both cases, the width of the outlet was assumed to be half of the top width of the channel.

Aerial photos and video footage indicate that a considerable portion of the vertical drop of each reach, particularly in the upper portion of the study area, occurs in short cascades. Because the horizontal lengths of these cascades are very short, they were assumed to occupy a negligible portion of the length of each reach and were not included in the simulation.

Elevation Profile

The original elevation profile obtained from USGS was retained for use in the model. The length and vertical drop of each reach in the model are given in Table 4. The elevation profile was checked for accuracy against topographic maps and other elevation benchmarks.

Model Calibration

To improve the simulation of the physical system, a number of sensitivity analyses were performed to assess the effect of various model parameters and assumptions on simulation results and to identify appropriate adjustments. Sensitivity analyses were performed to investigate the impact of the following parameters and model assumptions.

- Ridgeline and riparian shading
- Evaporation coefficient
- Longwave radiation coefficient
- Conduction coefficient
- Flow travel time
- Channel cross-section geometry
- Channel hydraulic properties including Manning's n and slope
- Depth of deep and shallow pools
- Proportioning of pools between deep and shallow
- Tributary temperatures
- Meteorological data

As a result of the above sensitivity analyses, changes were made to parameters used in the calculation of solar radiation and evaporation. The percentages of deep and shallow pools in two reaches near Box Canyons were also adjusted. These changes are described below, along with the basis for each change.

Solar Radiation

In the HSPF representation, the shortwave solar radiation absorbed by a river reach was approximated by the following equation:

$$QSR = 0.97 \times CFSAEX \times SOLRAD \times 10.0$$

Where:

QSR	=	shortwave radiation (kilocalorie [kcal]/square meter [m^2] / interval)
0.97	=	fraction of incident radiation that is absorbed (3 percent is reflected)

CFSAEX	=	ratio of radiation incident to water surface to radiation incident to gage where data were collected. Accounts for shading by vegetation and topographic features.
SOLRAD	=	solar radiation (langleys/interval)
10.0	=	conversion factor from langleys to kcal/m^2

The value of CFSAEX was adjusted to reflect differences in shading between the CIMIS Browns Valley station, where solar radiation values were measured, and the study area. The Browns Valley station is located in open foothill terrain to the west of Marysville and is not shaded by vegetation and topographic features. The Upper Yuba River canyons, on the other hand, are heavily shaded by topographic features and riparian vegetation.

On the Middle Yuba River, the value of CFSAEX was set to 0.5 in reaches between Milton Dam and East Fork Creek, and to 0.7 between East Fork Creek and Our House Dam. Upstream of East Fork Creek, the Middle Yuba River canyon is steep-walled and shades a considerable portion of the river channel. The river channel is also narrow, which increases the degree of riparian shading. Below East Fork Creek, the canyon walls and river channel widen, decreasing the effects of topographic and riparian shading.

On the South Yuba River, the value CFSAEX was set to 0.7. Aerial photos and videos show that the upper portion of the South Yuba River canyon is more open than the upper portion of the Middle Yuba River canyon. Further down, the ridgeline and riparian shading in the two canyons are similar.

Evaporation

Evaporative heat transport occurs when water evaporates from the water surface. The amount of heat lost depends on the latent heat of evaporation of water and the quantity of water evaporated. HSPF uses the following equation to calculate the amount of water evaporated:

$$EVAP = (KEVAP \times 10^{-9}) \times WIND \times (VPRESW - VPRESA)$$

Where:

EVAP	=	quantity of water evaporated (meter [m]/interval)
KEVAP	=	evaporation coefficient with typical values of 1 to 5
WIND	=	wind movement (m/interval)
VPRESW	=	saturation vapor pressure at the water surface (millibar [mbar])
VPRESA	=	vapor pressure of air above water surface (mbar)

The heat removed by evaporation is then calculated:

$$QT = HFACT \times EVAP$$

Where:

QE	=	heat loss due to evaporation (kcal/m2/interval)
HFACT	=	heat loss conversion factor (latent heat of vaporization multiplied by density of water)

The evaporation coefficient was reduced slightly from the default value to achieve a small reduction in evaporative cooling; this increased average daily simulated temperatures by a small amount, improving agreement with observed data. Tables 12 and 13 summarize changes to HSPF default parameters in this simulation.

TABLE 12
HSPF Parameters for Middle Yuba River

Heat Transfer Mechanism	Parameter	Value Used	Location
Shortwave Solar Radiation	CFSAEX	0.5	Milton Dam to East Fork Creek
		0.7	East Fork Creek to Our House Dam
Evaporation	KEVAP	2.00	Milton Dam to Our House Dam

TABLE 13
HSPF Parameters for South Yuba River

Heat Transfer Mechanism	Parameter	Value Used	Location
Shortwave Solar Radiation	CFSAEX	0.7	Lake Spaulding to Missouri Bar
Evaporation	KEVAP	1.60	Lake Spaulding to Missouri Bar

Percentage of Deep and Shallow Pools

The percentages of deep and shallow pools were adjusted from measured values in reaches 224 and 225, both of which are located on the Middle Yuba River between Milton Dam and East Fork Creek. The percentage of deep pools in reach 224 was reduced from 47.0 percent to 30.0 percent, while the percentage of shallow pools was increased from 8.9 percent to 25.9 percent. In reach 225, the percentage of deep pools was reduced from 68.7 percent to 30.0 percent, while the percentage of shallow pools was increased from 1.7 percent to 40.4 percent. The percentage of riffle and run habitat was not changed in either reach.

The percentages of deep and shallow pools in reaches 224 and 225 were changed because the high percentage of deep pools in both reaches resulted in simulated channel depths that were too deep. The range of simulated daily temperature variation (for example, the difference between daily minimum and maximum temperatures) is a function of the ratio of surface area to volume; when simulated depths are too great and the resulting surface area to volume ratio is too small, the daily range of temperatures is also too small. When the original measured percentages of deep and shallow pools were used in reaches 224 and 225, simulated temperatures at reach 225, which is located at the temperature monitoring station between Box Canyons 1 and 2, had a daily range of temperatures that was 1 to 2 degrees less than the observed range. Because the original measured estimates of deep and shallow pool habitat in these reaches were based on aerial photos and video footage, it was concluded that the extent of deep pool habitat may have been overestimated. As a result, the percentage of deep pools in both reaches was reduced to 30 percent of the overall length of each reach, increasing the daily range of simulated temperatures.

This approach was also applied on the South Yuba River to increase simulated daily temperature variation. The percentage of deep pools was reduced to 30 percent in reaches 209, 65, 69, 198, 196, 197, and 194, with a corresponding increase in the percentage of shallow pools. The percentages of riffles and runs were not changed from the original measured values for any of the reaches.

Tables 14 and 15 summarize changes made to the original habitat survey measurements.

TABLE 14
Changes to Habitat Survey Measurements: Middle Yuba River

Location	Reach	Measured % Deep Pools	Measured % Shallow Pools	Adjusted % Deep Pools	Adjusted % Shallow Pools
Milton Dam to East Fork Creek	224	47.00	8.90	30.00	25.90
	225	68.70	1.70	30.00	40.40

TABLE 15
Changes to Habitat Survey Measurements: South Yuba River

Location	Reach	Measured % Deep Pools	Measured % Shallow Pools	Adjusted % Deep Pools	Adjusted % Shallow Pools
Lake Spaulding to Diamond Creek	209	48.8	6.6	30.0	25.4
Scotchman Creek to Poorman Creek	65	46.8	7.4	30.0	24.2
	69	46.9	0	30.0	16.9
Poorman Creek to Jefferson Creek	198	35.5	23.7	30.0	29.2
Jefferson Creek to Missouri Bar	196	36.7	14.0	30.0	20.6
	197	49.1	9.6	30.0	28.7
	194	30.9	11.0	30	12.0

Figures 7 through 9 compare simulated and observed temperatures at three locations on the Middle Yuba River: between Box Canyons 1 and 2, above Wolf Creek, and below Kanaka Creek.

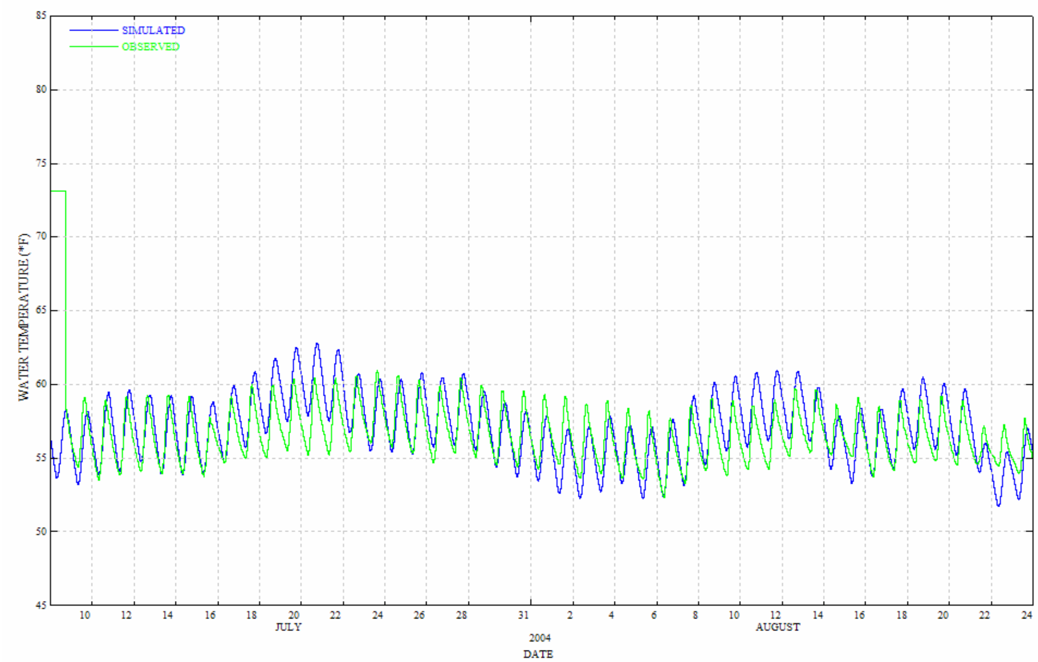

FIGURE 7
Comparison of Simulated and Observed Temperatures between Box Canyons 1 and 2 (RM 37)

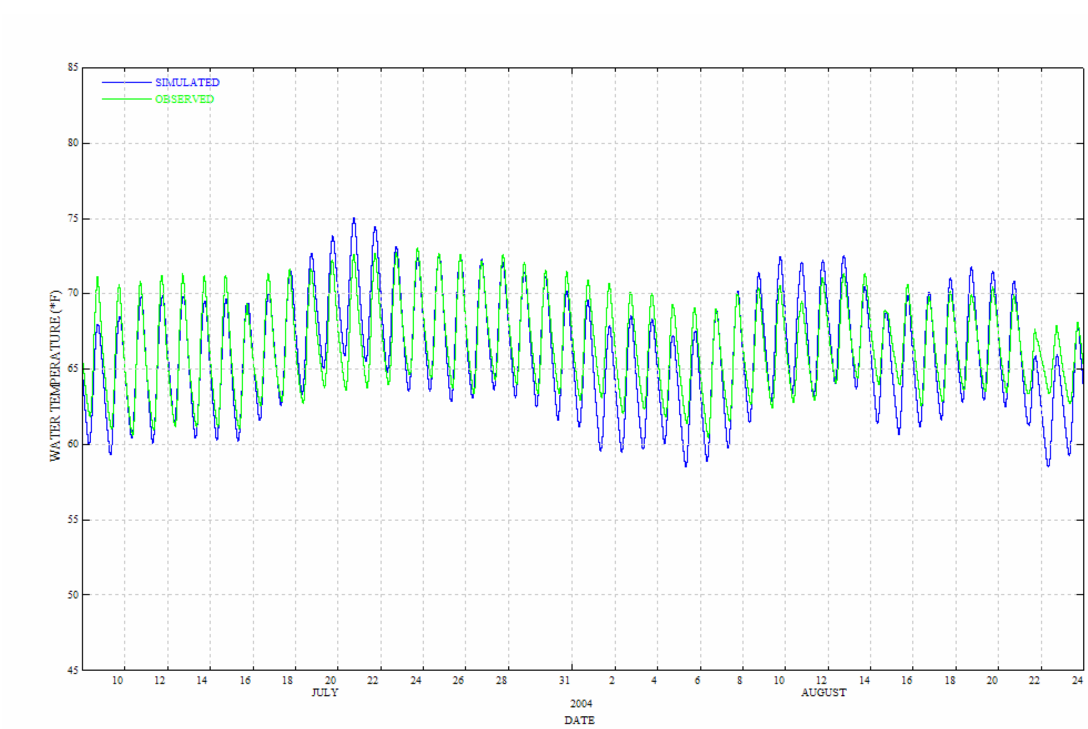

FIGURE 8
Comparison of Simulated and Observed Temperatures above Wolf Creek (RM 26)

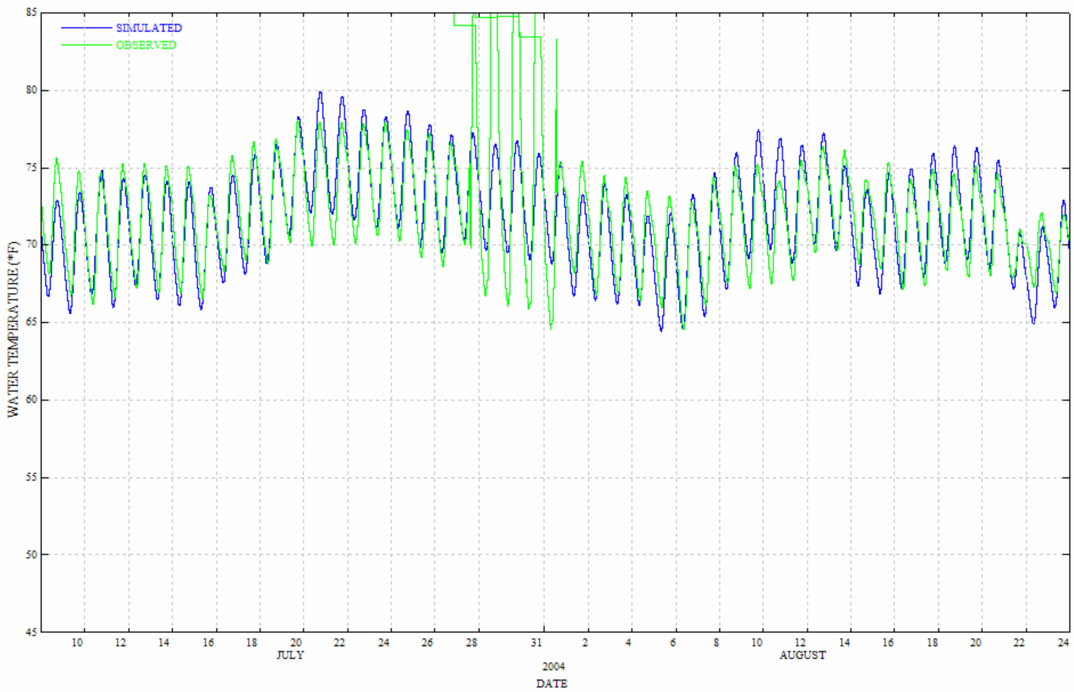

FIGURE 9
Comparison of Simulated and Observed Temperatures below Kanaka Creek (RM 16)
(Note: Temperature logger was above water surface July 28-August 1

Figures 10 and 11 compare simulated and observed temperatures at two locations on the South Yuba River: below Poorman Creek and at Missouri Bar.

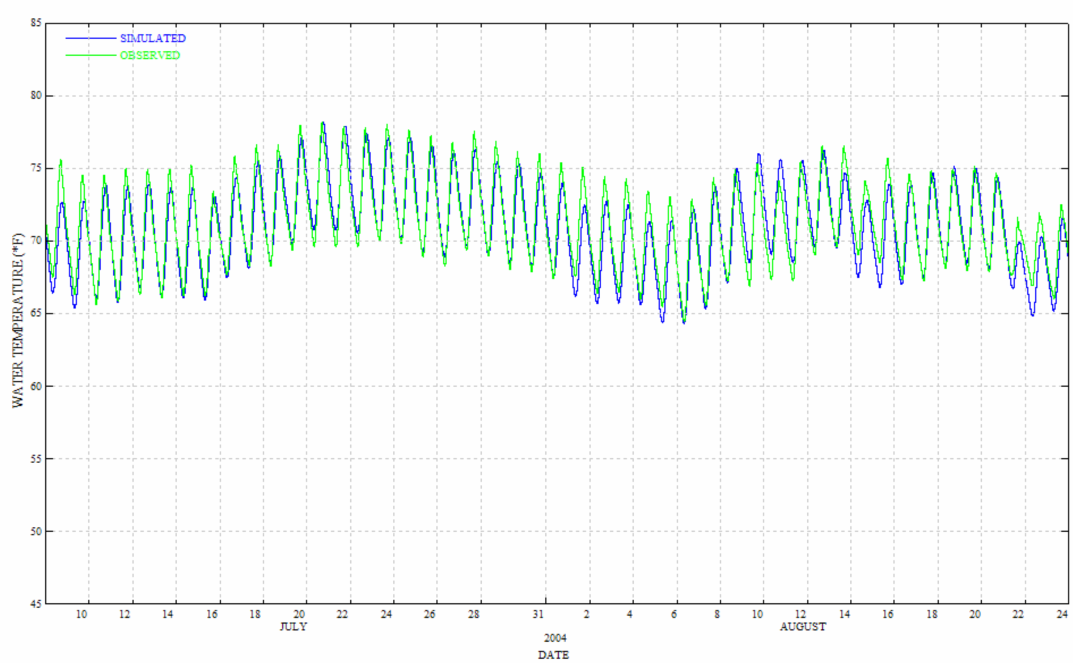

FIGURE 10
Comparison of Simulated and Observed Temperatures below Poorman Creek (RM 28)

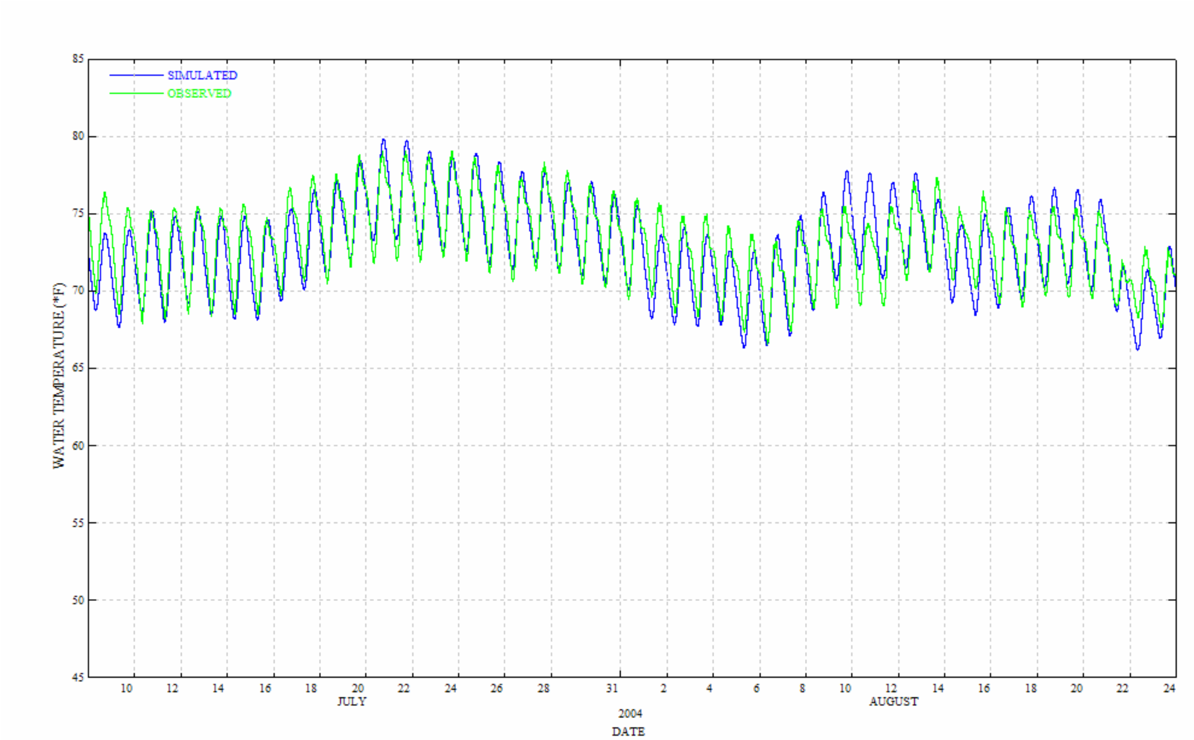

FIGURE 11
Comparison of Simulated and Observed Temperatures at Missouri Bar (RM 24)

Sample statistics were computed comparing hourly average values at each monitoring location. Tables 16 and 17 list sample statistics for July and August of 2004.

TABLE 16
Sample Statistics for Hourly Average Values: Middle Yuba River

		Monitoring Location		
Statistic	**Month**	**Between Box Canyons 1 and 2 (°F)**	**Above Wolf Creek (°F)**	**Below Kanaka Creek (°F)**
Observed Mean	July	57.0	66.5	72.4
	August	56.1	66.2	71.1
Simulated Mean	July	57.7	66.8	72.4
	August	56.3	65.4	70.9
Maximum Underprediction	July	2.4	3.2	2.8
	August	3.4	5.0	2.7
Maximum Overprediction	July	3.9	3.5	2.8
	August	3.6	2.7	3.0

TABLE 17
Sample Statistics for Hourly Average Values: South Yuba River

Statistic	Month	Monitoring Location SY below Poorman Creek (°F)	SY at Missouri Bar (°F)
Observed Mean	July	71.7	74.0
	August	70.2	71.7
Simulated Mean	July	71.7	73.7
	August	69.8	71.5
Maximum Underprediction	July	3.1	2.7
	August	3.1	2.9
Maximum Overprediction	July	2.5	2.3
	August	2.3	3.7

Error statistics also were computed at the three monitoring locations and are presented in Tables 18 and 19. Bias is defined here as the average of observed – simulated (for example, if simulated temperature are, on average, higher than observed temperature, the bias will be negative).

TABLE 18
Error Statistics for Hourly Average Values: Middle Yuba River

Statistic	Month	Monitoring Location Between Box Canyons 1 and 2 (°F)	Above Wolf Creek (°F)	Below Kanaka Creek (°F)
Bias	July	-0.7	-0.2	0.0
	August	-0.2	0.8	0.2
Mean Absolute Error	July	1.2	1.1	1.0
	August	1.2	1.4	1.0
Root Mean Squared Error	July	1.4	1.3	1.2
	August	1.5	1.7	1.2
Standard Deviation	July	1.2	1.3	1.5
	August	1.5	1.5	1.2

TABLE 19
Error Statistics for Hourly Average Values: South Yuba River

Statistic	Month	Monitoring Location: SY below Poorman Creek (°F)	Monitoring Location: SY at Missouri Bar (°F)
Bias	July	0.0	0.3
	August	0.4	0.2
Mean Absolute Error	July	0.8	0.8
	August	0.9	1.1
Root Mean Squared Error	July	1.0	1.0
	August	1.1	1.3
Standard Deviation	July	1.0	1.0
	August	1.1	1.3

The error statistics indicated that the model produced a reasonable simulation of observed temperatures. The bias values, which are indicative of systematic errors, were generally small. The mean absolute error at all locations was less than 1.2°F with the exception of Wolf Creek in August. The root mean squared error in all locations was not much larger than the mean absolute error, indicating that large errors were few in number.

Results

The model was used to provide a screening-level estimate of the effect of increased releases from Milton Dam and Lake Spaulding on downstream water temperatures. On the Middle Yuba River, where the summer release from Milton Dam was approximately 4 cfs during the summer of 2004, simulations were performed with 10, 20, 30, 40, and 50 cfs releases. On the South Yuba River, where the summer release from Lake Spaulding was approximately 11 cfs during the summer of 2004, simulations were performed with 20, 30, 40, and 50 cfs releases. In all cases, it was assumed that release temperatures remain equal to observed temperatures below Milton Dam and Lake Spaulding and do not change with increased flows. Figures 12 through 14 compare simulated water temperatures at 4, 10, 20, 30, 40, and 50 cfs release levels at each of the three monitoring locations on the Middle Yuba River.

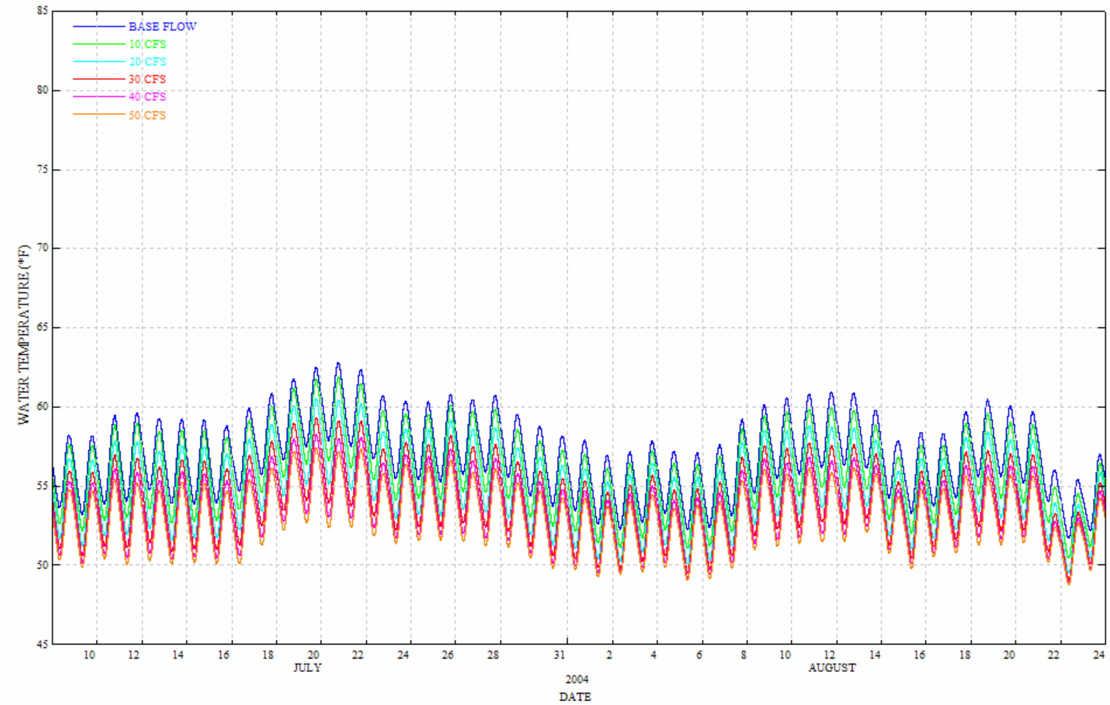

FIGURE 12
Comparison of Simulated Temperatures between Box Canyons 1 and 2 for Base (4 cfs), 10, 20, 30, 40, and 50 cfs Flow Levels

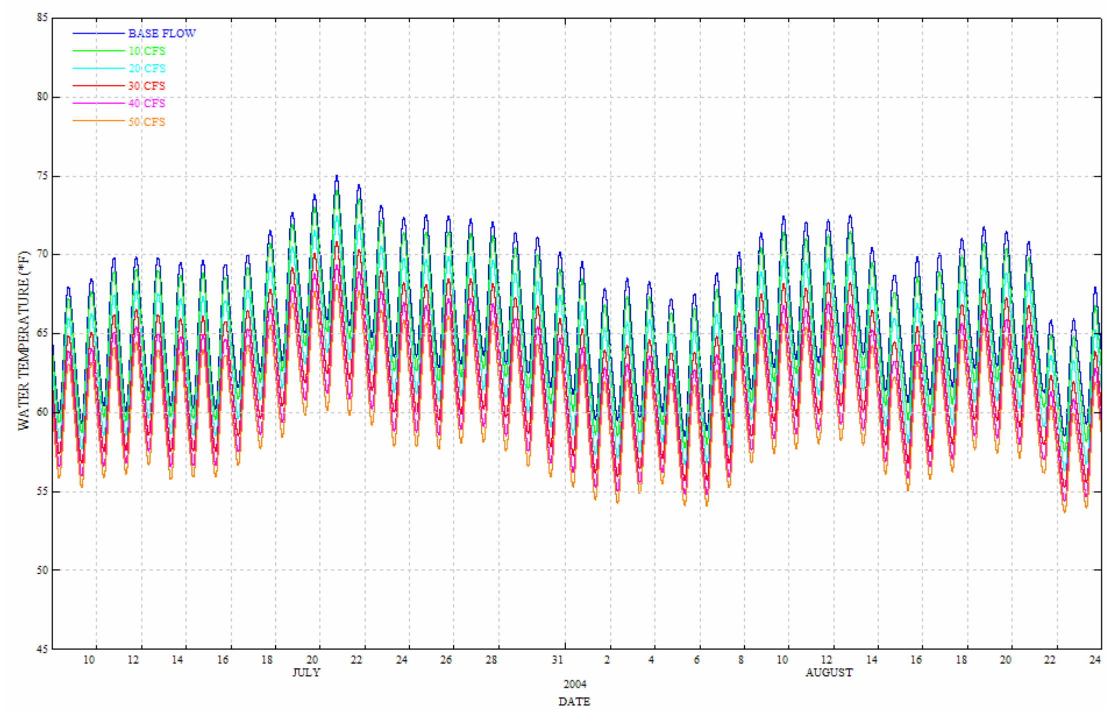

FIGURE 13
Comparison of Simulated Temperatures above Wolf Creek for Base (4 cfs), 10, 20, 30, 40, and 50 cfs Flow Levels

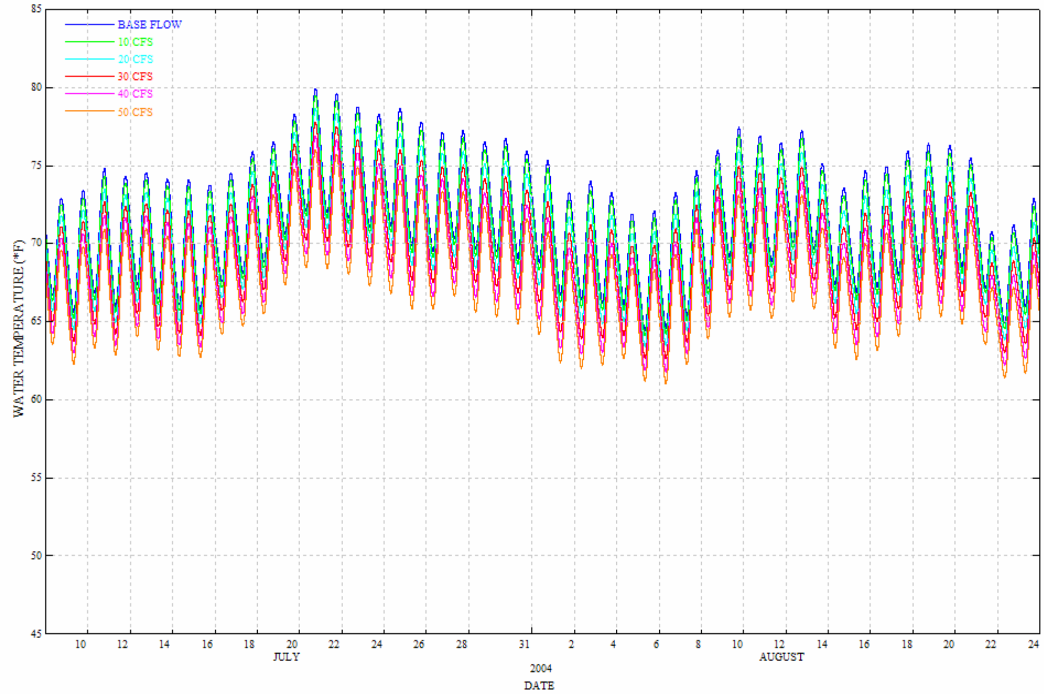

FIGURE 14
Comparison of Simulated Temperatures below Kanaka Creek for
Base (4 cfs), 10, 20, 30, 40, and 50 cfs Flow Levels

Figures 15 and 16 compare simulated water temperatures at 11, 20, 30, 40, and 50 cfs release levels at both of the monitoring locations on the South Yuba River.

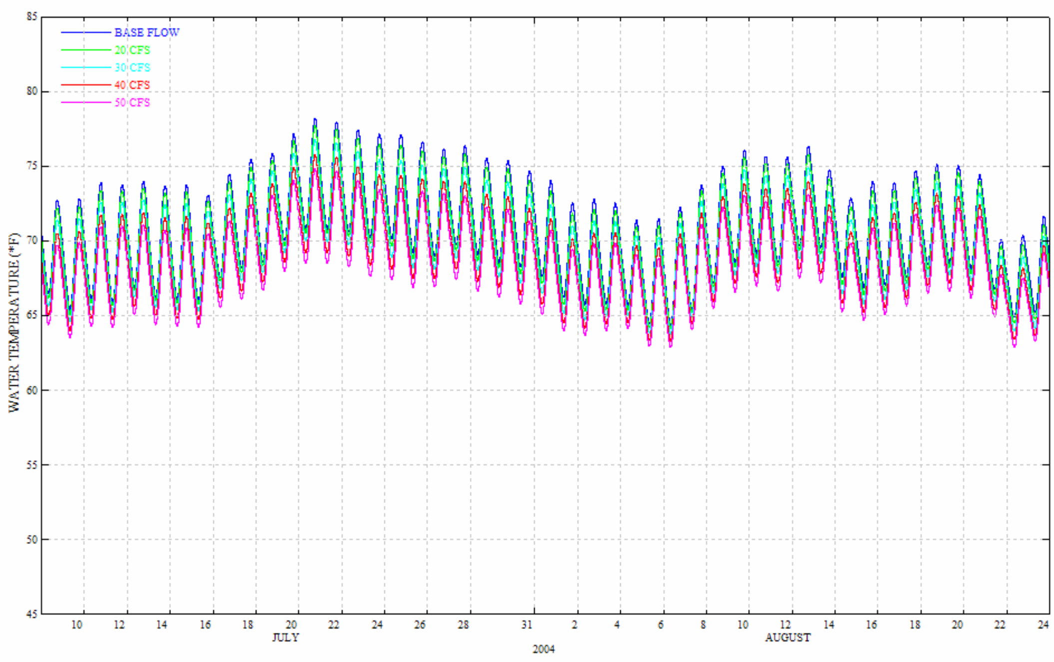

FIGURE 15
Comparison of Simulated Temperatures below Poorman Creek for
Base (11 cfs), 20, 30, 40, and 50 cfs Flow Levels

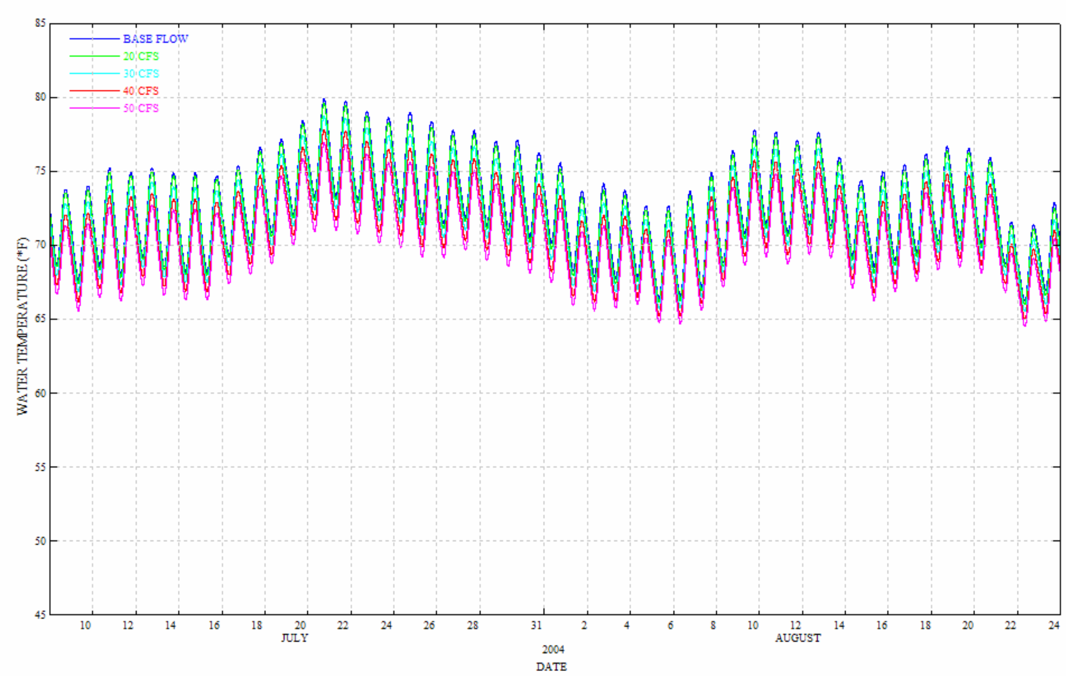

FIGURE 16
Comparison of Simulated Temperatures at Missouri Bar for
Base (11 cfs), 20, 30, 40, and 50 cfs Flow Levels

Seven-day moving average results for the three monitoring locations on the Middle Yuba River are shown in Figures 17 through 19. The figures indicate that increasing the Milton release from 4 cfs to 50 cfs has the potential to reduce average temperatures by 4°F to 5°F between Box Canyons 1 and 2, 5°F to 6°F above Wolf Creek, and 4°F to 5°F below Kanaka Creek.

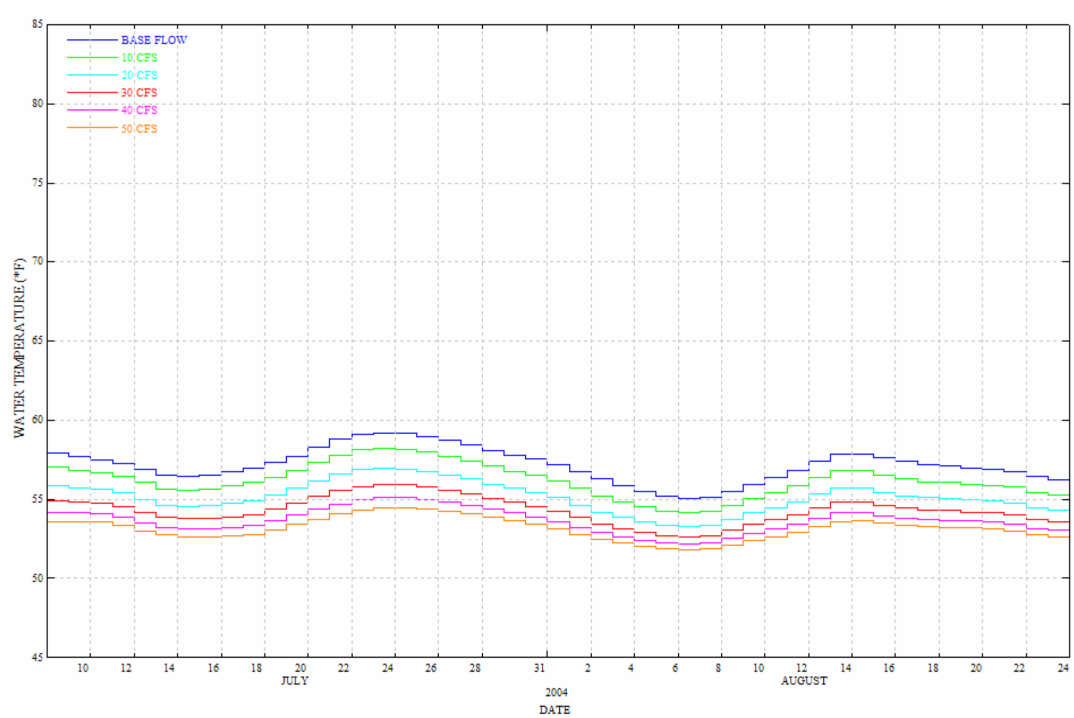

FIGURE 17
Comparison of 7-day Average Simulated Temperatures between Box Canyons 1 and 2 for
Base (4 cfs), 10, 20, 30, 40, and 50 cfs Flow Levels

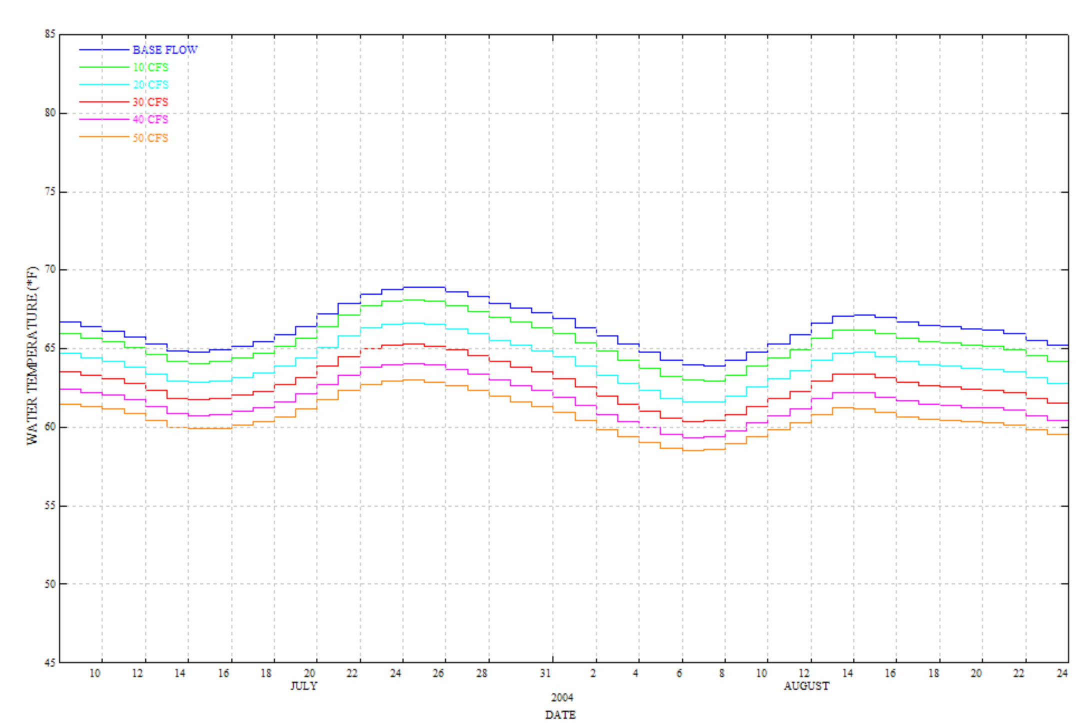

FIGURE 18
Comparison of 7-day Average Simulated Temperatures above Wolf Creek for Base (4 cfs), 10, 20, 30, 40, and 50 cfs Flow Levels

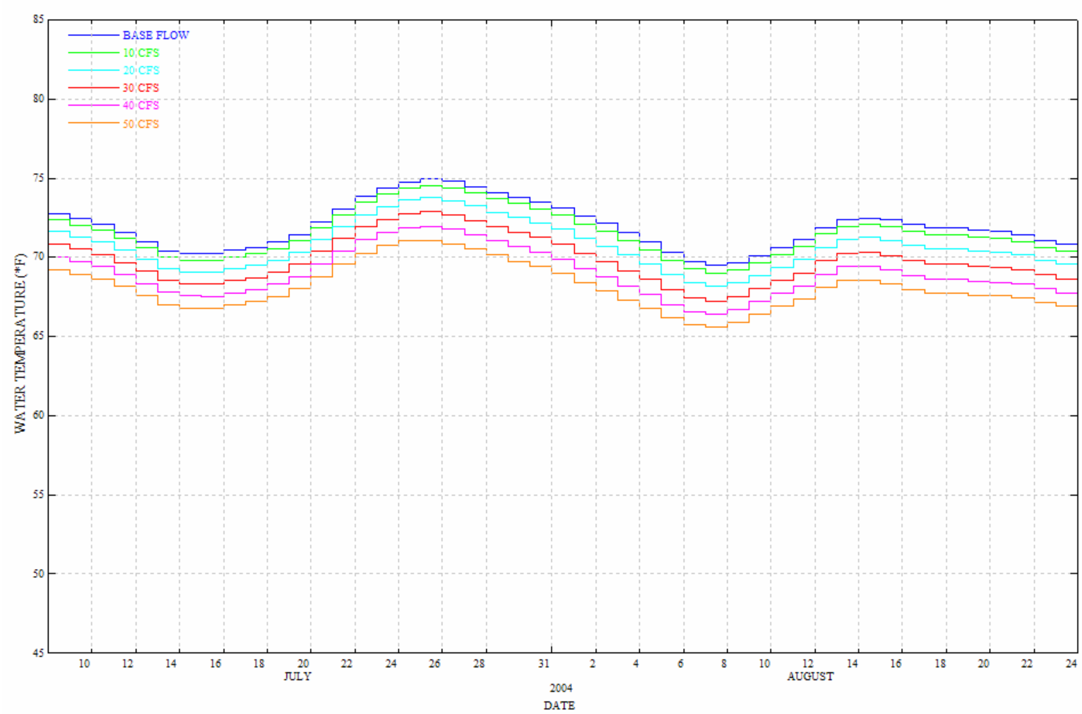

FIGURE 19
Comparison of 7-day Average Simulated Temperatures below Kanaka Creek for Base (4 cfs), 10, 20, 30, 40, and 50 cfs Flow Levels

Seven-day backward moving average results for the two monitoring locations on the South Yuba River are shown in Figures 20 and 21. The figures indicate that increasing the release from Lake Spaulding from 11 cfs to 50 cfs has the potential to reduce average temperatures by 2°F to 3°F below Poorman Creek and at Missouri Bar.

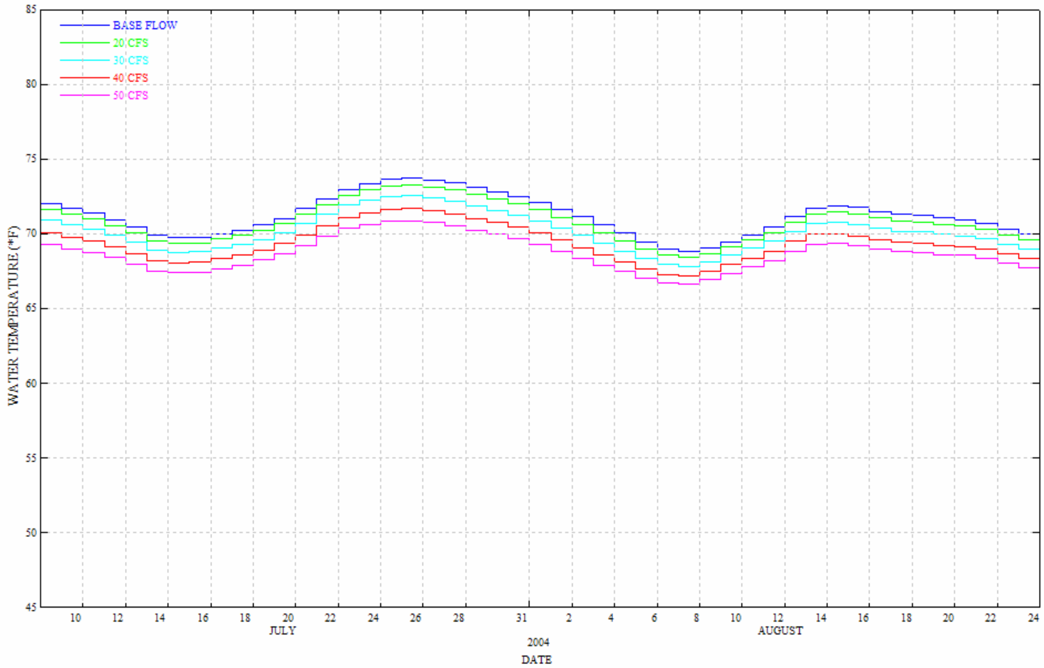

FIGURE 20
Comparison of 7-day Average Simulated Temperatures below Poorman Creek for Base (11 cfs), 20, 30, 40, and 50 cfs Flow Levels

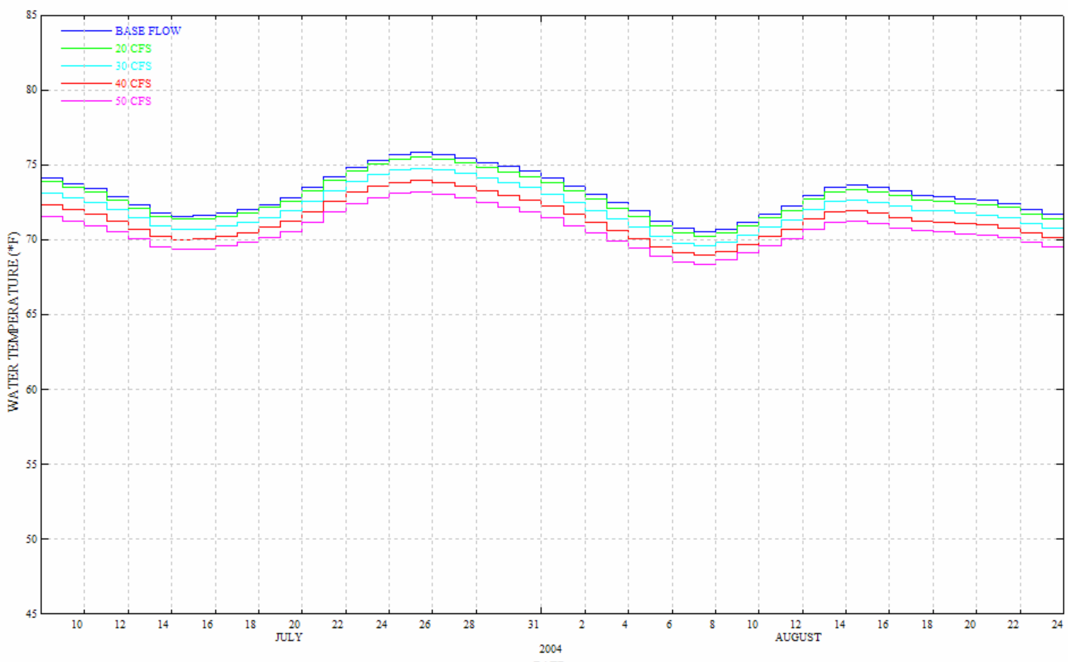

FIGURE 21
Comparison of 7-day Average Simulated Temperatures at Missouri Bar for Base (11 cfs), 20, 30, 40, and 50 cfs Flow Levels